



Review article

An objective review of the technological developments for radial pulse diagnosis in Traditional Chinese Medicine[☆]

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ARTICLE INFO

Article history:

Received 20 May 2015

Received in revised form 27 June 2015

Accepted 28 June 2015

Keywords:

Traditional Chinese Medicine

Pulse diagnosis

Signal processing

Pattern recognition

Pulse sensors

Pulse acquisition system

Review

ABSTRACT

Introduction: Pulse palpation is an important diagnostic tool in Traditional Chinese Medicine (TCM) and related Oriental medicine systems. However, mastering pulse diagnosis requires long-term experience and remains subjective up to a certain degree even in an advanced stage of practice. Accordingly, considerable research efforts have been spent to objectively measure the radial pulse and in further consequence automate Oriental pulse diagnosis by means of technological aids. This article gives the first comprehensive review about the current state of the art of this field covering topics such as developed pulse acquisition systems, suggested data preprocessing and feature extraction methods, and proposed classification approaches. Furthermore, persisting problems are pointed out and recommendations for future research directions are given.

Methods: A literature search was conducted using scientific databases such as PubMed and ScienceDirect. ResearchGate, Academia, and GoogleScholar were used as additional literature sources. Key search terms were *Chinese pulse diagnosis, Oriental pulse diagnosis, wrist pulse, standardization, objectification, automation, technological aids, sensors, data processing, classification, devices, acquisition systems* and combinations and synonyms of these terms. Additionally, the reference lists of found articles were scanned to identify further relevant literature.

Results: A total of 111 references were included into the review. Four main research themes emerged from the literature: (1) pulse waveform acquisition, (2) pulse waveform preprocessing, (3) pulse waveform feature extraction, (4) classifiers and classification objectives.

Conclusion: Automating TCM pulse diagnosis by means of technological aids is a very active research field. Nevertheless, much remains to be done in terms of both technological developments and standardization of procedures.

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[☆] This article belongs to the Special Issue on Diagnostic Techniques and Outcome Measures for Integrated Health.

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1. Introduction

Pulse palpation is an important diagnostic tool in Traditional Chinese Medicine (TCM) and related Oriental medicine systems [1–6]. However, mastering pulse diagnosis requires long-term experience and remains subjective up to a certain degree even in an advanced stage of practice [7]. Therefore, it has been discussed controversially in contemporary scientific literature [8–14]. In the last decades, considerable research efforts have been put into the attempt to objectify, quantify, and automate Oriental pulse diagnosis by employing modern sensor and data acquisition technologies, data processing strategies, and pattern classification approaches.

The objective of this article is to provide a comprehensive review about the research efforts so far spent in this field, the progresses made, and the challenges that remain to be addressed. Firstly the technique of manual pulse palpation and diagnosis as currently performed by practitioners is described and the challenges for its objectification. This is followed by a summary of the contemporary research areas of TCM pulse diagnosis. The main part of this article in Section 5 provides a comprehensive description of the technological components necessary for automating TCM pulse diagnosis. Finally, a conclusion and recommendations for further research are provided.

2. Methods

A literature search was conducted using the scientific databases PubMed, ScienceDirect, and IEEEExplore. ResearchGate, Academia, and GoogleScholar were used as additional literature sources. Key search terms were *Chinese pulse diagnosis, Oriental pulse diagnosis, wrist pulse, standardization, objectification, automation, technological aids, sensors, data processing, classification, devices, acquisition systems* and combinations and synonyms of these terms. Additionally, the reference lists of found articles were scanned to identify further relevant literature. From the 193 references found, 111 were included into the review. The main inclusion criterion was that the references contained significant content concerning technologies for Oriental wrist pulse diagnosis. References written in Asian languages were only included in case they had an English abstract containing relevant information with a significant level of detail.

3. Basic technique of TCM pulse diagnosis and difficulties for its objectification

In Oriental as well as Western medicine, the pulse is considered as a fundamental signal of life, carrying essential information about a person's health status [4]. While Western medicine mainly uses ECG signals recorded from the patient's chest for diagnosis of heart problems, TCM practitioners focus on palpating the pulse

pressure wave on the radial artery at three distinct positions (cun, guan, chi) on the right and left forearm close to the wrist.

The basic rationale behind TCM wrist pulse diagnosis is that pathologic changes in the body are reflected in the radial pulse [15,16]. This premise is supported by Western clinical research studies, which have found evidence for loss of arterial elasticity and alterations in pulse amplitude, rhythm, and shape in patients with cardiovascular disease, hypertension, diabetes, etc. [15]. In several articles [3,8,15], the pulse pressure wave is described as the superposition of a forward travelling wave caused by the ventricular output of blood and a phase-shifted backward travelling wave reflected from the peripheral blood vessels. Malinauskas et al. [17] indicate that the forward travelling component is correlated with information about the heart itself and the backward travelling wave contains information about the arterial tree and the organs it flows through.

In the course of history, different systems for pulse pressure wave interpretation have been suggested. One commonly used approach is to analyse the overall pulse quality by palpating the cun, guan, and chi positions concurrently while applying different levels of pressure. Another widespread method investigates each pulse position individually, with each position having an association with a specific body area (upper, middle, lower burner) or organ system (heart, liver, kidneys, lungs, spleen, pericardium, small intestine, gall bladder, bladder, large intestine, stomach, triple burner).

In ancient Oriental medicine texts, various pulse qualities have been described. The model most prevalent in contemporary Traditional Chinese Medicine is based on the Bin Hu Mai Xue, Zhen Jia Shu Yao, and Zhen Jia Zhen Gyan [18,19] and covers the following 28 pulse qualities [20]: floating, sunken, slow, rapid, surging, fine, vacuous, replete, long, short, slippery, rough, string-like, tight, soggy, moderate, faint, weak, dissipated, hollow, drumskin, firm, hidden, stirred, intermittent, bound, skipping, and racing.

One difficulty and challenge of objectifying TCM pulse diagnosis is that classical wrist pulse patterns are mainly described in a qualitative way and are not clearly defined quantitatively. In [20,21,22], it is put as follows: TCM pulse reading is still based on subjective concepts and analogies to differentiate pulse patterns, such as “pressing the string of a musical instrument” for the string-like pulse, “pressing a rope” for the tight pulse, or “beads rolling” for the slippery pulse. Magnitudes of pulse patterns are not clearly defined. For instance, a fine pulse is described as “a little bit stronger” than a faint pulse. Furthermore, the descriptions of certain pulse patterns show overlaps. While some patterns describe a single dimension of a pulse condition (e.g. string-like, rapid, floating), others concern “compound” pulse conditions (e.g. the replete pulse being a composite of the elements long, large, forceful, and stiff). Among practitioners, the fuzziness and ambiguity of pulse concepts make it difficult to study and master pulse diagnosis and often lead to a low inter-rater and intra-rater

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